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COMPARISON OF GENERALIZED TRANSPORT AND  
SEMIKINETIC MODEL :  
PREDICTION FOR EVOLUTION OF A  
DENSITY ENHANCEMENT IN THE POLAR WIND

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ABSTRACT

The evolution of density, drift velocity and parallel temperature following a cold plasma enhancement in an  $H^+$  polar wind are obtained with semikinetik and generalized transport codes. The principal difference in the results is that whereas steep bulk parameter gradients persist in the generalized transport case, such gradients are readily dissipated in the semikinetik calculations, owing to ion velocity dispersion. Inclusion of large heat flow coefficients reduces the gradients seen in the generalized transport results.

I. INTRODUCTION

In studying polar plasma outflow, the most frequently adopted approaches are the employment of generalized transport and semikinetik models. Generalized transport models involve the solution of a set of  $N$  moment equations solving for  $N+1$  bulk parameters, completed by a closure relation for the highest bulk parameter considered (usually heat flow). One of the principal advantages of the generalized transport approach is its efficiency in computing time; however, many problems may require a detailed consideration of ion distribution functions beyond that which is available from generalized transport models. The accuracy in describing a plasma with generalized transport models increases with the order of moment equations employed but the highest order equations can be complicated and difficult to solve. By comparison, in solving the Boltzmann equation, the kinetic model in essence solves an infinite hierarchy of moment equations, and it yields the full distribution function; again, however, at the expense of efficiency.

Since both generalized transport [1,2] and semikinetik approach [3,4] are used extensively in studying polar cap phenomena, it is important to compare results from the two models for certain basic problems of interest. One outcome of such comparisons might be an improved understanding of the accuracy and limitations of using generalized transport models in global problems, where application of semikinetik methods are impractical. Such comparison has been made for steady-state polar wind [5] in which good agreement was found. In this paper, we compare, for the first time, results for a time-dependent phenomenon, the evolution of a density perturbation

imposed in the polar wind. For the generalized transport model, we solve the continuity, momentum and energy transport equations which include temperature anisotropies. The set of equations are closed by a heuristic equation for the heat flow

$$q_{\parallel,\perp} = \epsilon \eta n k T_{\parallel,\perp} v_{th} \quad (1)$$

where  $\epsilon$  is 1 (-1) for negative (positive) temperature gradients,  $\eta$  controls the magnitude of  $q$  and is taken to be 0.12 in the comparisons shown here,  $v_{th}$  is the parallel thermal speed, and  $n$ ,  $k$  and  $T$  have their usual meanings. Details of Eq. (1) and the transport equations can be found in [6]. For the semikinetic approach, a particle-in-cell method was used. The parallel motions of simulation  $H^+$  ion gyrocenters are subjected to forces including gravity, magnetic mirror force and electric field. The electric field is obtained by solving the Boltzmann relation and assuming quasineutrality for the electrons and ions [4]. In this example study, we simulate only  $H^+$  from  $1.47 R_E$  to  $10 R_E$ . The ions are injected from below the lower boundary as the upgoing half of a drifting bi-Maxwellian distribution. The parameters of this injected distribution are: density ( $500 \text{ cm}^{-3}$ ), drift velocity (20 km/s), and temperature (3560K) for both  $T_{\parallel}$  and  $T_{\perp}$ .

## RESULTS

To compare the time-dependent transport model and the semikinetic model, we examine for our case study the time-evolution of the ion density, drift speed and parallel temperature of a non-drifting cold localized plasma enhancement in the supersonic  $H^+$  polar wind. The plasma enhancement is represented at time  $t = 0$  by

$$n_{enh}(r) = p n_{pw}(r) e^{-\frac{1}{2}(\frac{r-r_p}{\sigma})^2} \quad (2)$$

where  $n_{pw}(r)$  is the steady state polar wind density.  $n_{enh}(r)$  is therefore a gaussian distribution along  $r$  of width  $\sigma$  and a peak value of  $p$  times  $n_{pw}$  at  $r = r_p$ . We chose  $p$ ,  $\sigma$  and  $r_p$  to be 5, 1260 km and 15600 km respectively. The plasma density enhancement has zero flow velocity initially and has an ion temperature of 500°K for both  $T_{\parallel}$  and  $T_{\perp}$ .

The reduced distribution function for  $H^+$  shown in Figure 1 and 2a indicates a two-stream distribution. A two-stream distribution results in a higher "effective temperature" in comparison to the separate streams. In using the transport model, we will study the evolution of the cold plasma imposed on the polar wind for both interpretations: one has the initial bulk parameters taken directly from the velocity moments of the distribution function which are obtained from the semikinetic model (dashed line, Figure 3). This is done to see how the bulk parameters with the same initial values, irrespective of the distribution function, will evolve in time

under the two models. This will be referred to as Case A. The other has the initial bulk parameters (dotted line, Figure 3) calculated according to the following equations

$$\bar{v} = \frac{n_0 v_0 + n_1 v_1}{n_0 + n_1} \quad (3)$$

$$\bar{T}_\alpha = \frac{n_0 T_{\alpha 0} + n_1 T_{\alpha 1}}{n_0 + n_1} \quad (4)$$

where  $\bar{v}$  and  $\bar{T}_\alpha$  are the average flow velocity and ion temperature,  $\alpha$  stands for  $\parallel$  or  $\perp$ .  $n$  and  $v$  are the number density and flow velocity of the polar wind (subscript 0) and density enhancement (subscript 1). (4) will result in a lower average temperature than the case using the moment over the "two-stream" distribution. This alternative condition will be case B. Results of both cases will be compared with those of the semikinetic model.

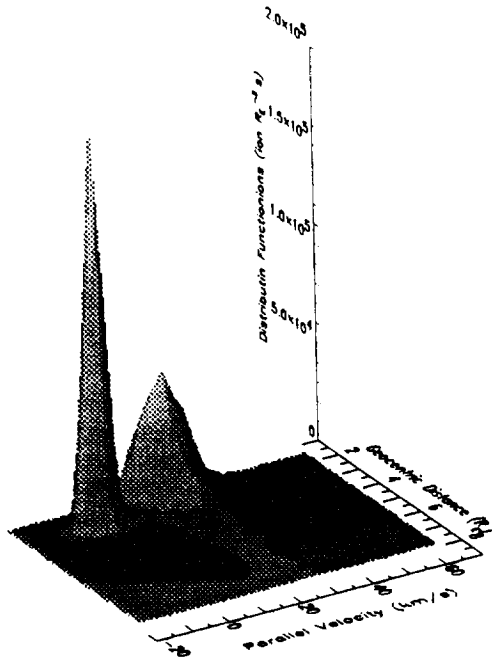


Figure 1. Non-drifting cold plasma density enhancement in  $H^+$  polar wind at  $t = 0$

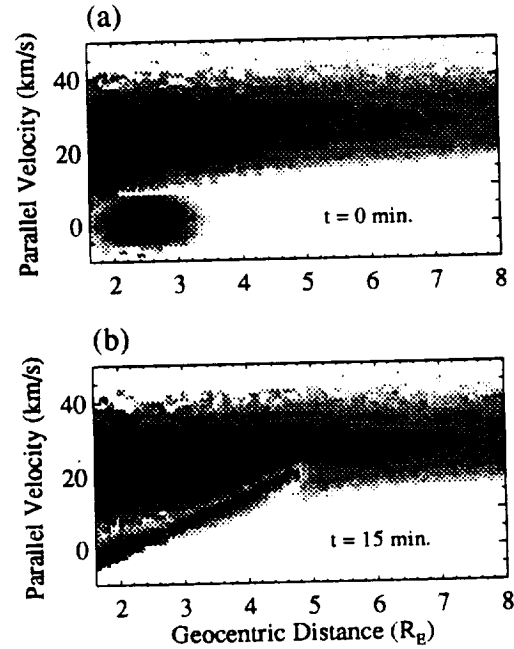


Figure 2. Reduced distribution of cold plasma in polar wind at (a)  $t = 0$  and (b)  $t = 15$  min.

Figure 3 shows the density, drift velocity and parallel temperature at  $t = 0$  and 15 minutes after the density enhancement was imposed. After 15 minutes, the density profile of the semikinetic model (solid curve) is rather smooth, the density enhancement having been largely dissipated by dispersion up and down the field line (Figure 2b). The ions in the density enhancement are also accelerated away from the peak due to the opposite

sign of the electric field (which depends on the density gradient) above and below the peak of the density enhancement. At 15 min the low velocity (solid curve, Figure 3b) is caused by the presence of the density enhancement which has low drift speed. The elevated parallel temperature (solid curve, Figure 3c) is due to the effective temperature of the two streams.

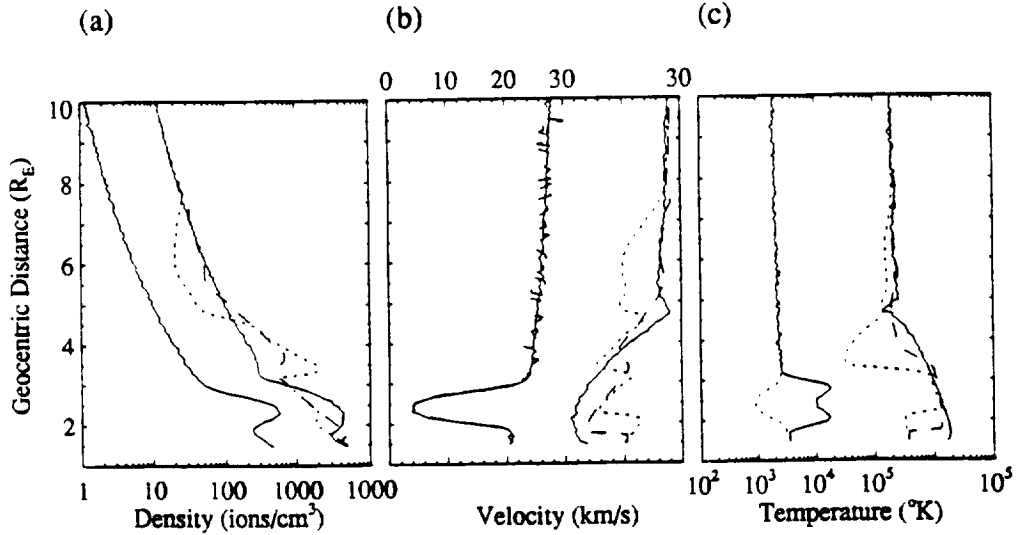


Figure 3. Bulk parameters at  $t = 0$  and  $t = 15$  min of semikinetic model (solid), Case A transport model (dashed), and Case B transport model (dotted). In these plots, the 15 minutes are displaced by log factors of 10 and 100 for the density and parallel temperature, respectively, and by a linear increment of 20 km/s for the parallel velocity.

The results of the two types of initial conditions in the transport model show significant differences. The density profile at 15 min for Case A (dashed curve, Figure 3a) have two distinctive density enhancements in the form of shocks around  $2 R_E$  and  $3.5 R_E$ . These two density enhancements correspond to similar shock structures in the velocity and temperature profiles at the same altitudes. The smaller density enhancement at  $2 R_E$  is a local minimum in speed and local maximum in temperature, while the one at  $3.5 R_E$  is a local minimum in speed and temperature. The bulk parameters obtained from the transport model may be characterized by the locations of the shocks and local minima/maxima, but the formation of these features are difficult to explain without a knowledge of the distribution function. Indeed, in the present study, the distribution function obtained from the semikinetic model does not even support several of the features seen in the results of the transport model.

For Case B, the density profile has developed a cavity around  $6 R_E$ . This cavity has a low drift speed. The velocity profile has multiple steep

gradients which are more pronounced than those of case A.

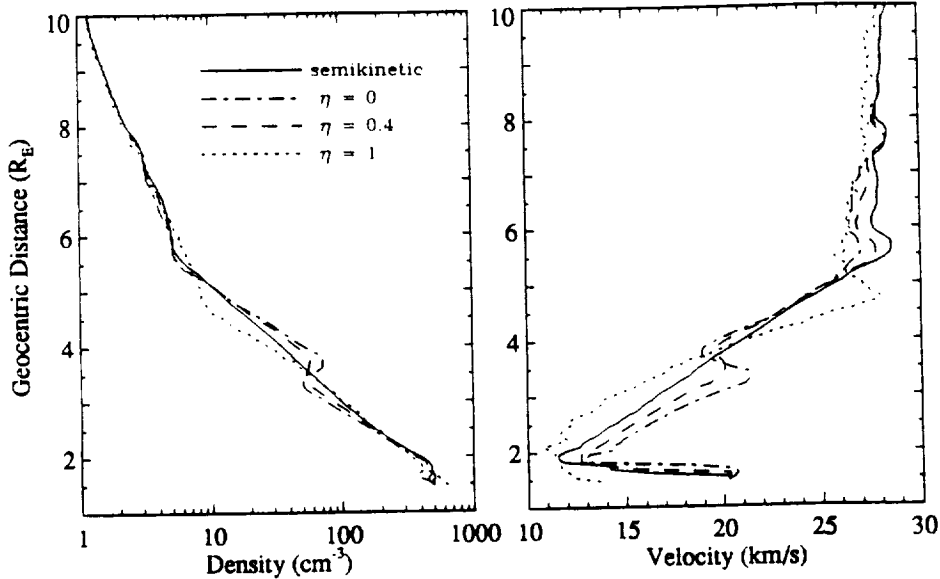


Figure 4. Density and velocity profiles of Case A transport model with different heat flow parameter  $\eta$ .

The main difference between the semikinetic model and transport model results are the smoother and more rounded profiles of the semikinetic model as a result of velocity dispersion, which is the spreading out of ions due to a spectrum of ion velocity. Within the context of the transport models of this order, the effects of such dispersion on bulk parameters can be partially mimicked by simply increasing the heat flow parameter. Figure 4 shows a series of density and velocity profiles for heat flow parameter  $\eta = 0, 0.4$  and 1 respectively, for transport model Case A. For large heat flux ( $\eta = 1$ , dotted curve), there are no sharp density gradients and the results are much closer to those of the semikinetic model (solid curves).

### III. DISCUSSION

The present study has shown that the transport model in general tends to produce significant differences with those of a semikinetic model. The most significant difference is in the absence of shocks in the semikinetic code. The elimination of shocks in the transport model by the inclusion of a large heat flux raises the question of whether shocks so often seen in hydrodynamic models, are due to a lack of shock-reducing mechanisms. We have seen that the profiles of various velocity moments of the semikinetic model are smooth as a result of dispersion due to a spectrum of ion velocities. Alternatively, we can say that phase mixing, which is a thermal damping mechanism in the kinetic model [7], may be responsible for the

smooth profiles, and may be found in even higher moments of the transport equations. Therefore, more sophisticated transport models, which include more accurate forms of heat flow, stress release across the shock boundaries, and possibly thermal wave damping, may produce more comparable results with the semikinetic model. However, a very sophisticated transport model may become so complicated to solve that its advantages over the kinetic model in its original simplicity and time efficiency will be lost. It is also important to note that those aspects of agreement between the models for the problem we have considered here, a relatively simple one of plasma flow evolving on open field lines, do not necessarily indicate optimism about the use of transport models for general problems. For example, in phenomena involving closed field lines, where magnetic mirroring and extensive formation of multiple streams occurs, develop of approaches within the transport model framework which can match results with those of semikinetic models is likely to be much more difficult.

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